Effect of Digitally Modulated Signals on Multipactor Breakdown

Apostolos L. Sounas, Juan R. Mosig and Michael Mattes
Laboratory of Electromagnetics and Acoustics (LEMA)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
CH-1015 Lausanne, Switzerland
Email: apostolos.sounas@epfl.ch

***Abstract*—This paper studies the effect of digitally modulated signals on the evolution of the multipaction phenomenon. Multipactor is numerically analyzed in a parallel plates waveguide for a variety of common digital modulation techniques. Breakdown power thresholds and the temporal evolution of the particle population are computed. Results demonstrate that the phenomenon may be remarkably affected depending on the applied modulation scheme.**

***Index Terms*—digital modulation; microwave breakdown; multipactor**

I. Introduction

The increased demand for high data rates and qualitative services in satellite communications leads to the need for higher power operation levels. This fact, combined with the vacuum conditions, makes satellite systems susceptible to the multipactor effect, an RF breakdown discharge which can disturb the electrical performance of the devices [1], [2]. Serious problems may appear, like the increase of the noise level, the growth of return losses or even the device destruction in case that a corona discharge is triggered. Therefore, multipaction prediction constitutes a crucial issue in the design of payload components, such as microwave filters, connectors and waveguides.

A lot of studies on the multipactor effect have been performed for a single harmonic excitation [3]–[8]. However, modern satellite communication systems transmit more complex signals. Due to the increasing number of users, multiple carriers are used. Moreover, various digital modulation techniques are applied in order to efficiently boost the available bandwidth of each channel. To this end, multipaction analysis under realistic signals has triggered research interest in recent years [9]–[11].

The present work focuses on digital modulated signals and studies how they may affect the multipactor phenomenon. Due to the abrupt changes in the driven signal, digital modulation schemes may perturb the conditions needed for a resonant multipaction procedure. In order to qualitatively study these perturbations, multipaction is computationally analyzed for the case of a parallel plates configuration. The implemented algorithm is able to estimate the electron population between the plates for a variety of common digital modulation techniques, such as phase shift keying and quadrature amplitude modulation (PSK and QAM).

II. Model Description

In this work, the electron distribution between the parallel plates is modeled by using the constant-u theory [2]. According to this, the secondary electrons are all emitted with the same speed, composing an infinitely thin electron sheet. Then, the total electron population can be represented by a single effective particle, also referred to as macroparticle.

The electron sheet is assumed to oscillate between the two plates in the direction perpendicular to the surfaces, driven by the applied electric field. The dynamics of the macroparticle are analysed by an efficient numerical tracker based on high order Runge-Kutta differential schemes. The tracker considers the TEM mode for a single modulated carrier that can be generally described by the following equation

$$E(t) = \frac{A_{\mathrm{mod}}(t)}{d} \sin[2\pi f_{\mathrm{mod}}(t)t + \phi_{\mathrm{mod}}(t)], \qquad (1)$$

where A_{mod}, f_{mod} and ϕ_{mod} are the amplitude, frequency and phase of the modulated signal, respectively, and d is the gap between the parallel plates. Depending on the applied modulation scheme, the amplitude, frequency and phase may sharply vary after a symbol change, thus affecting, the electrons motion.

When the electron sheet impinges on a plate, the particles population may increase or decrease depending on the impact velocity. In order to estimate the number of electrons after impact events the Secondary Emission Yield (SEY) model formulated in [12] has been used. This model has been preferred among others since it takes elastically reflected electrons into account which can remarkably affect the multipaction process [13].

III. Multipactor Analysis

The analysis reveals interesting results for the behavior of multipactor under different modulation schemes. As an example, consider two modulation schemes frequently used in satellite communications, namely PSK and QAM of 8th order. Then, a harmonic carrier, applied to a 1 mm parallel plates gap, is modulated by a random bit stream. The constellation diagram of the modulated signal for both studied schemes is presented in Fig. 1. Two different frequencies of 1 GHz and 2 GHz are studied while symbol rates of 20 MBd and 40 MBd are considered respectively for the two cases, corresponding to

978-88-907018-1-8/13/$31.00 ©2013 IEEE

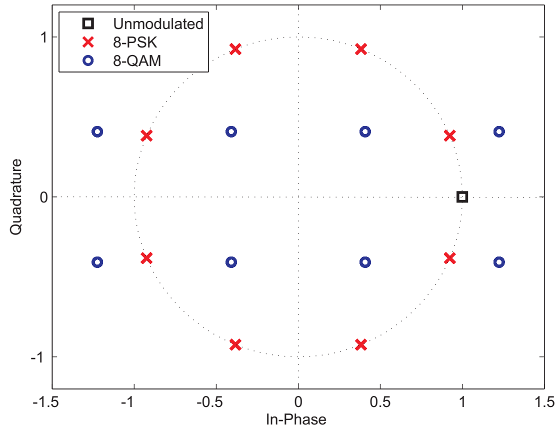


Fig. 1. Constellation diagram of the 8-QAM and 8-PSK studied modulation schemes.

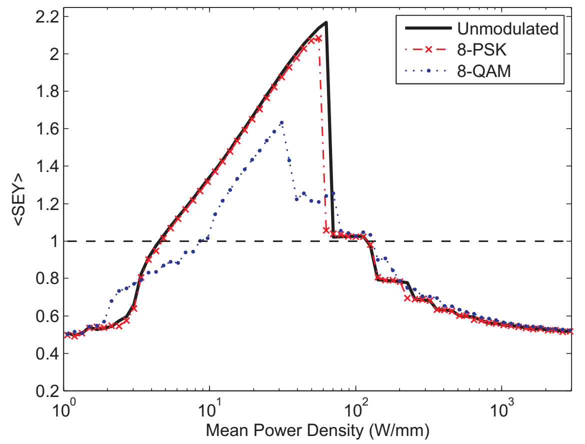
a fixed ratio between the symbol period and the carrier period equal to $T_{symbol}/T_{carrier} = 50$. A sufficiently long time of 10000 RF periods has been simulated in order to take into account the statistical behavior of the modulated signal.

A figure of merit that allows to decide whether multipactor breakdown might take place is the geometric mean SEY, $\langle \text{SEY} \rangle$. It represents the average number of emitted electrons per impact. If this number is larger than one, the electron population grows exponentially, thus a breakdown occurs. Fig. 2 compares the results obtained in terms of the $\langle \text{SEY} \rangle$ as a function of the mean power density for the examined 8-QAM and 8-PSK cases. Additionally, corresponding data for an unmodulated harmonic carrier are also presented.

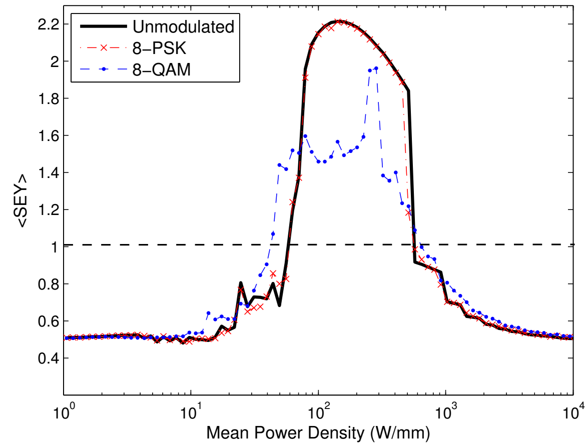
As one can observe, multipaction for the 8-PSK signal follows a very similar behavior as in the case of the unmodulated carrier. The phase switches seem to affect only slightly the evolution of the electron population. However, a different tendency can be noticed for the 8-QAM modulation. Depending on the operation frequency, the first multipactor threshold may be remarkably shifted to higher or to lower power values compared to the unmodulated case. Moreover, for both frequencies, the mean SEY values appear diminished compared to the corresponding values of the unmodulated signal along the multipactor region. This clearly means that the multipaction onset takes longer to develop.

A better perspective of how a modulated signal affects multipaction can be obtained by studying the temporal behavior of the phenomenon for certain values of input power. As an example, the 1 GHz case is studied in time domain for the specific power density of 7 W/mm. This case is interesting since the two modulation schemes result in a different tendency regarding the population evolution of the particles. Figs. 3 and 4 illustrate how the electron motion as well as the secondary emission are perturbed after symbol changes.

In the PSK case, the resonant motion breaks due to the phase changes (Fig. 3(b)), leading to an absorption process



(a)



(b)

Fig. 2. Geometric mean SEY as a function of input power density (mean power values). A carrier frequency of (a) 1 GHz and (b) 2 GHz is considered.

(Fig. 3(c)). However, the electrons regain synchronization with the RF field in a short time period. Hence, the augmentative behavior on the population evolution is not significantly affected.

On the other hand, in the QAM case, the modulated signal affects the multipaction process in a more complicated way since, apart from phase variations, sharp changes on the electric field amplitude are also possible. Contrary to the PSK signal, a change of a QAM symbol may really perturb the evolution of multipaction phenomenon, as Fig. 4 depicts. More specifically, in the examined case when the field amplitude changes from the higher to the lower level the resonant condition is broken, like in the PSK example. But, in this case, the resonance cannot be regained, leading to a decreasing process of the particles population. It can be shown that the resonance is again obtained after a symbol change to the higher amplitude level. Therefore, one can notice "ON" and "OFF" multipactor regions for the higher and the lower amplitude level respectively, that is, time periods when

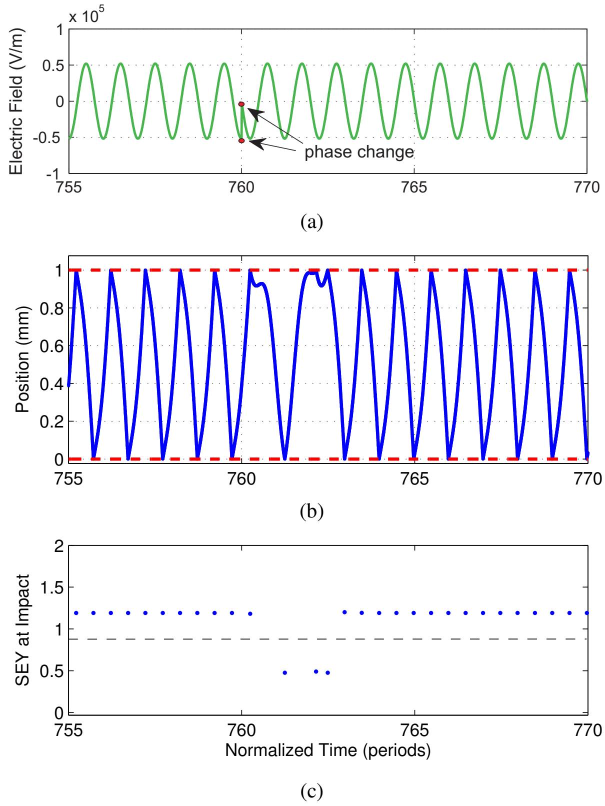


Fig. 3. Temporal analysis of multipactor effect for the studied 8-PSK signal. A carrier frequency of 1 GHz and a mean power density of P=7 W/mm are considered. The figure depicts (b) the electron motion and (c) the SEY values at impact events. (a) For representation purposes the electric field is also included.

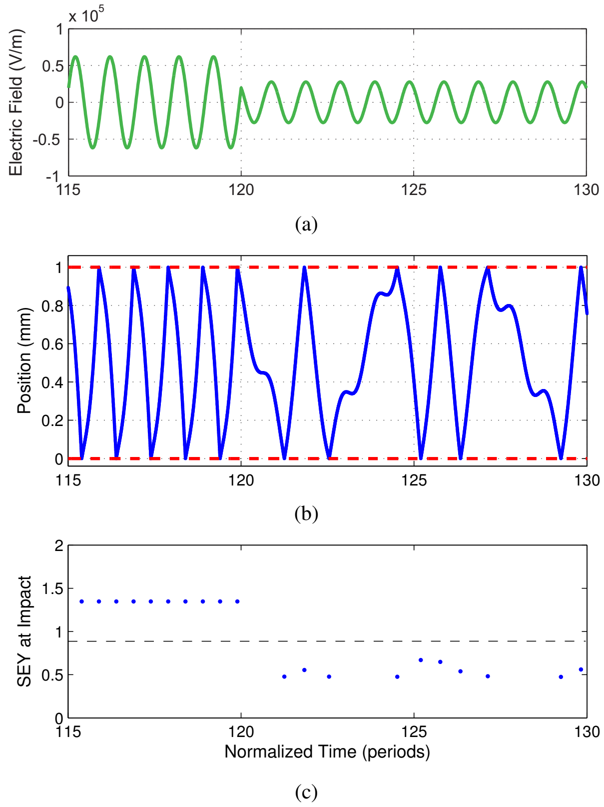


Fig. 4. Temporal analysis of multipactor effect for the studied 8-QAM signal. A carrier frequency of 1 GHz and a mean power density of P=7 W/mm are considered. The figure depicts (b) the electron motion and (c) the SEY values at impact events. (a) For representation purposes the electric field is also included.

multipactor conditions are satisfied or not. This behavior of the QAM signal leads to an oscillating evolution of the electron population, as Fig. 5 shows.

IV. Conclusion

This paper investigated the influence of digital modulation on the evolution of the multipaction phenomenon.Results for 8-PSK and 8-QAM modulation techniques have been presented. They demonstrate that multipaction for PSK follows a similar behavior like in the case of an unmodulated single carrier. On the other hand, amplitude modulation schemes, like QAM, can signifficantly affect the phenomenon. In this case, the classical multipaction analysis of an unmodulated harmonic is not sufficient since the multipactor threshold may notably shifted to higher or lower power levels.

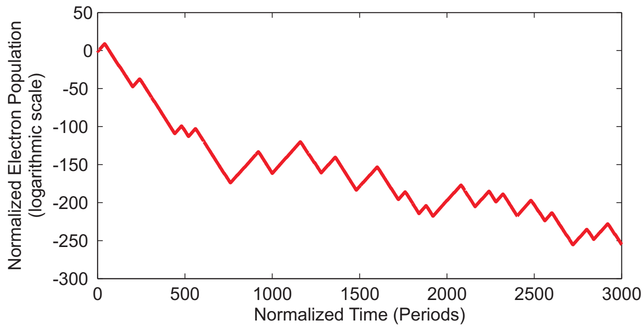


Fig. 5. Evolution of electron population (normalized regarding to the initial population) for the examined 8-QAM case. A carrier frequency of 1 GHz and a mean power density of P=7 W/mm are considered.

References

[1] R. Kishek, Y. Lau, L. Ang, A. Valfells, and R. Gilgenbach, "Multipactor discharge on metals and dielectrics: Historical review and recent theories," *Physics of Plasmas*, vol. 5, pp. 2120–2126, 1998.

[2] J. Vaughan, "Multipactor," *Electron Devices, IEEE Transactions on*, vol. 35, no. 7, pp. 1172 –1180, Jul. 1988.

[3] R. Woo, "Multipacting discharges between coaxial electrodes," *Journal of Applied Physics*, vol. 39, pp. 1528–1533, 1968.

[4] R. Kishek and Y. Y. Lau, "Interaction of multipactor discharge and rf circuit," *Phys. Rev. Lett.*, vol. 75, pp. 1218–1221, Aug. 1995.

[5] S. Riyopoulos, "Multipactor saturation due to space-charge-induced debunching," *Physics of Plasmas*, vol. 4, p. 1448, 1997.

[6] R. Udiljak, D. Anderson, M. Lisak, V. Semenov, and J. Puech, "Multipactor in a coaxial transmission line. i. analytical study," *Physics of Plasmas*, vol. 14, p. 33508, 2007.

[7] A. G. Sazontov, V. E. Nechaev, and N. K. Vdovicheva, "The susceptibility diagrams of a multipactor discharge on a dielectric: Effects of rf magnetic field," *Applied Physics Letters*, vol. 98, p. 161503, 2011.

[8] E. Sorolla and M. Mattes, "Multipactor saturation in parallel-plate waveguides," *Physics of Plasmas*, vol. 19, p. 72304, 2012.

[9] S. Anza, M. Mattes, C. Vicente, J. Gil, D. Raboso, V. Boria, and B. Gimeno, "Multipactor theory for multicarrier signals," *Physics of Plasmas*, vol. 18, p. 032105, Mar. 2011.

[10] J.-C. Angevain, L. Drioli, P. Delgado, and C. Mangenot, "A boundary function for multicarrier multipaction analysis," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, Mar. 2009, pp. 2158 –2161.

[11] V. Semenov, M. Buyanova, D. Anderson, M. Lisak, R. Udiljak, and J. Puech, "Multipactor in microwave transmission systems using quadrature phase-shift keying," *Plasma Science, IEEE Transactions on*, vol. 38, no. 4, pp. 915 –922, Apr. 2010.

[12] J. de Lara, F. Perez, M. Alfonseca, L. Galan, I. Montero, E. Roman, and D. Garcia-Baquero, "Multipactor prediction for on-board spacecraft rf equipment with the mest software tool," *Plasma Science, IEEE Transactions on*, vol. 34, no. 2, pp. 476 – 484, Apr. 2006.

[13] V. Semenov, E. Rakova, D. Anderson, M. Lisak, and J. Puech, "Importance of reflection of low-energy electrons on multipactor susceptibility diagrams for narrow gaps," *Plasma Science, IEEE Transactions on*, vol. 37, no. 9, pp. 1774 –1781, Sept. 2009.